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Integrating Industry 4.0 in Higher Education Using Challenge-Based Learning: An Intervention in Operations Management

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Abstract: Industry 4.0 is predicted to significantly transform the jobs and skill profiles of workers. Implications for higher education may involve dramatic changes in the demand for knowledge and skills. In response to this, a Challenge-Based Learning (CBL) intervention was designed with the aim of developing working skills for the future of work on undergraduate students by embedding the Industry 4.0 theme in the Operations Management curricula. The CBL intervention was implemented in two different academic terms at a UK university, and views from 302 undergraduate business students were captured using document analysis. The benefits are reported in terms of knowledge acquisition and the application and development of key desirable working abilities for the future. The results suggest that CBL increases students' understanding of Industry 4.0 issues in real-life settings. It also provides an environment for soft-skills training for skills, including collaboration, communication, planning and problem-solving. This study provides a blueprint for the implementation of CBL in the Operations Management curricula. The study validates existing findings obtained from the application of CBL in other disciplines. Whilst the proposed CBL intervention might be easily replicated in business schools in the UK, the findings on students' experiences might not be directly generalized to other contexts or disciplines.

Keywords: Industry 4.0; curriculum design; educational innovation; soft skills; experiential learning; higher education; professional education

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Citation: Vilalta-Perdomo, E.; Michel-Villarreal, R.; Thierry-Aguilera, R. Integrating Industry 4.0 in Higher Education Using Challenge-Based Learning: An Intervention in Operations Management. *Educ. Sci.* **2022**, *12*, 663. https://doi.org/10.3390/educsci12100663

Academic Editor: Eleanor Dommett

Received: 5 July 2022
Accepted: 10 September 2022
Published: 29 September 2022

1. Introduction

The purpose of this paper is to propose an augmented framework for the use of Challenge-Based Learning (CBL) in Operations Management (OM) education. The aim of such modification is to support undergraduate students in acquiring the hard and soft skills demanded in the future workplace. The development of the augmented framework considers embedding the Industry 4.0 theme in the Operations Management curricula. Findings from its implementation are presented based on students' first-hand experiences.

Industry 4.0 is an umbrella term referring to a new industrial stage, facilitated by the convergence of manufacturing systems with emergent Information and Communication Technologies (ICTs), giving rise to the so-called cyber-physical systems [1]. This convergence, driven by artificial intelligence, blockchain, the internet of things and other ICTs, is predicted to affect "every corner of the factory and supply chain" [2] (p. 2) and significantly transform the jobs and skill profiles of workers [3]. In Operations Management (OM), several benefits are expected, including a reduction in manufacturing costs, reduction in processing times, increased process flexibility and improved coordination of the supply chain [4,5].

Nevertheless, one of the main challenges for the successful adoption of Industry 4.0 technologies is the demand for highly skilled workers [6]. This confirms the essential role that education and training will play in achieving effective and efficient Industry 4.0 implementations [7]. This view is shared by Olsen and Tomlin (2020), who highlighted how important it is "to equip our students with the knowledge and skills required to manage the new operations and supply chain realities that will emerge" [8] (p. 113).

Following this concern, Teixeira et al. [9] indicated the necessity for "HEIs, businesses and governments to update strategic plans and define the implementation of specific actions for Industry 4.0" (p. 3). Teixeira et al. [9] also recognized that this triad (academia, business and government) plays a fundamental role in the development of innovation [10] and recommended actions to develop this strategic update, such as to increase stakeholder engagement, establish innovative resources for higher education students and create postgraduate courses in creative Industry 4.0.

Salah et al. [11] suggest that one possible road to place previous ideas into practice is to upgrade the current academic curricula to train and familiarize future generations of students with Industry 4.0 innovations to support their societies' welfare. Some specific teaching and learning approaches have been recommended for this purpose, including Education 4.0. This is a student-centered technology-based teaching and learning approach, where students become protagonists of their own learning by means of advanced Industry 4.0 technologies [12,13]. This approach can be extended to other teaching and learning approaches designed to create internships, monitoring projects and work on project-based activities.

For instance, Flexible Manufacturing Systems have been used as a didactic environment, where engineering students develop their final projects linked to Industry 4.0 problems [7]. However, to focus on acquiring factual knowledge and skills by means of technology-based and competency-based learning approaches does not appear to be sufficient to achieve an effective education [14]. As reported by Morcke et al. [15] "when students learned affectively, socially, culturally, aesthetically, or ethically from experience, it was not possible to specify goals or assess them objectively but that did not mean such types of learning were unimportant" (p. 853).

This suggests the need of some sort of integrative learning when assessing the acquisition of competencies difficult to operationalize; for instance, some medical colleges use 'entrustable professional activities' by "taking educational outcomes and translating them into an essential, observable and measurable activity that a professional should be able to perform" [16] (p. 5).

Similarly, Hariharasudan and Kot (2018) suggested organizing 'Learning by Doing' activities to increase students' readiness for Industry 4.0, as this approach increases the opportunities to apply new skills in different scenarios. Therefore, in this paper, rather than focusing on Industry 4.0 technologies in education (i.e., Education 4.0), we propose an approach to build 'learning by doing' experiences in real life business situations (Challenge-Based Learning, CBL), where students may acquire the hard and soft skills required to successfully navigate in an Industry 4.0 working environment.

As in many other disciplines, the OM academic community faces the challenge of reconsidering the knowledge and skills that students need to acquire to better fit the demands for Industry 4.0 solutions within real-world businesses. Specifically, a recurring issue in relation to OM teaching is acknowledging the relevance of what is taught. In the case of Industry 4.0, the integration of hard and soft skills is considered essential [9]. OM professionals are expected to be equipped with complex problem-solving skills, creativity and critical thinking [17]; however, the lack of digital culture and digital skills is a critical constraint to Industry 4.0 adoption [18].

Overall, the current research on how to prepare future professionals for an Industry 4.0 working environment is incipient. *The Changing Nature of Work* report by the World Bank [19] sheds some light regarding the skills needed. The report highlights the imminent global challenge concerning the preparation of future professionals for a digitalized workplace. Regarding the management of operations in the future, professionals must be capable of making decisions in volatile and unbounded circumstances, because the data available might be too limited (uncertainty), too excessive (Big Data) or of low-quality (e.g., 'fake news').

Digital approaches and the use of robots and Artificial Intelligence might be a palliative but not a substitute for supporting such highly complex decision-making. The report summarizes a set of desirable working skills for the future—namely, critical thinking, problem solving, technological know-how and soft skills. This paper reports lessons learned from the application of a cutting-edge approach to educational innovation [20], known as Challenge-Based Learning (CBL), adopted to introduce university students to Industry 4.0, whilst developing the desirable working abilities for the future identified by The World Bank [19].

CBL is an approach that aligns the acquisition of disciplinary knowledge with the development of soft skills by confronting students with real-life challenges [21]. Growing evidence suggest that CBL facilitates the development of key desirable working abilities for the future [22–25]. However, this remains understudied in the context of non-STEM disciplines, including business studies and operations management.

This paper serves as a reference for further implementations of CBL within OM education by means of an augmented CBL framework. We also suggest how to include Industry 4.0 practical elements in the OM curricula. Furthermore, this study validates existing findings obtained from the application of CBL in other disciplines. Finally, the benefits are reported in terms of knowledge acquisition and the application and development of key desirable working abilities for the future.

Accordingly, the structure of this paper considers the following sections: First is the background, where the main principles of CBL are explained. Second is the research methods, where the design and implementation of the intervention and the data collection and analysis are described. Third is the results, where a range of themes and codes regarding how students experienced CBL is presented in terms of four dimensions: the challenge, teamwork, feelings and CBL. Fourth is the discussion, where the evidence collected confirms that the proposed CBL framework within OM classrooms is beneficial for students' acquisition of hard and soft skills. Finally, a series of conclusions presents some limitations to the current work, invites further research and delineates a possible degree of transferability to other disciplines.

2. Background

Challenge-Based Learning (CBL) is a multidisciplinary teaching and learning approach that aims to increase students' understanding of the technology used in their daily lives to solve real-world problems [26]. This concept is part of a larger collaborative project known as Apple Classrooms of Tomorrow—Today (ACOT2), a 1985 initiative involving government-funded schools, universities, research agencies and Apple Computer, Inc. to introduce technology as a tool for learning, thinking, collaborating and communicating, inside classrooms [27]. CBL is constituted by interlinked steps that guide the design and implementation of learning spaces, which are not confined by classroom walls. The impact of these learning spaces can be found beyond traditional boundaries, as CBL also considers activities to share findings with the wider community—activities that make use of physical and digital means [28].

As shown in Figure 1, the CBL framework comprises three consecutive phases supported by an ongoing process of documenting, reflecting and sharing [29]. In stage 1 (engage), students and/or other stakeholders move from broad concepts (big ideas) to challenges through a process of essential questioning. In stage 2 (investigate), students acquire the knowledge needed to develop solutions to the challenges. This research process is assisted using guiding questions, guiding activities and guiding resources—all of them developed by the educators.

In phase 3 (act), grounded solutions are developed, implemented in a real setting and evaluated. In this phase, students also receive feedback and learn from their success/failure. Throughout these three stages, the students document their experience and reflect on their learning process. Sharing solutions and reflections beyond the classroom is an important aspect of CBL. This can be accomplished through web-based communities or public events with participants of the community [26].

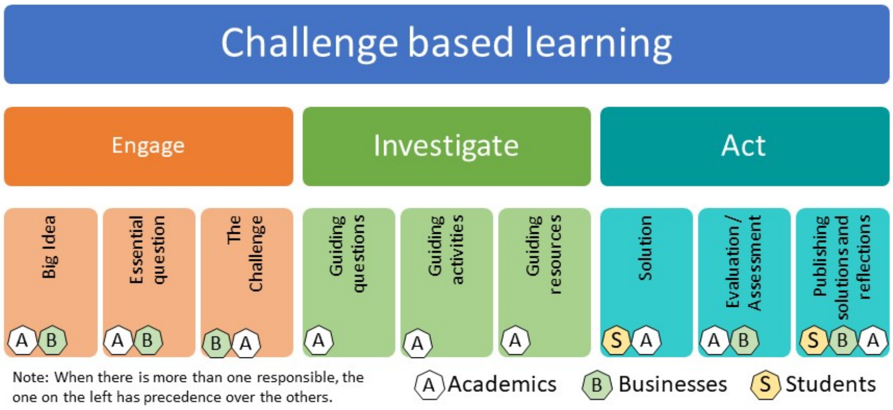

Figure 1. Challenge-Based Learning framework. Source: Adapted from Apple (2010).

Challenge-Based Learning (CBL) shows similitudes with other teaching and learning approaches. In this sense, it might be argued that CBL integrates aspects of other educational practices, such as Problem-Based Learning (PBL), Project-Oriented Learning (POL) and contextual teaching and learning [30]. Common aspects among these approaches are critical thinking, problem-solving, collaborative learning, autonomy and others [23,31].

The main difference between CBL and other approaches lies in the use of real-life situations and the need for real, concrete solutions. Unlike POL or PBL, which often use predefined controlled situations or fictitious problem situations, CBL confronts students with an open, relevant problem for which there is no pre-made (universal) solution [23]; this tends to increase uncertainty and the need for self-direction.

Since its conception, CBL has been widely and successfully implemented across different levels of education, from elementary school (ages 8–11) to university [32]. The approach has been used to teach a variety of topics, such as aerospace engineering [33], mechanical and mechatronics engineering [34], nursing [24,35], software development [31] and sustainable development engineering [23]. These studies have documented multiple benefits, which include the improvement of soft skills.

Soft skills are defined broadly as a "set of skills, behaviors and personal qualities that enable people to effectively navigate their environment, perform well and achieve their goals" [36] (p. 9). In a recent systematic review, Chalkiadaki [37] summarized a wide range of soft skills, including critical thinking, team working, collaboration, communication and others. Given that The World Bank [19] does not provide a framework for the identification of soft skills, this work adopts Chalkiadaki's [37] framework as guidance to identify soft skills that students can develop through CBL.

Overall, existing evidence suggests that CBL facilitates the application and development of key desirable working abilities for the future [19], including a variety of soft skills [29]. This is summarized in Table 1.

Table 1. The World Bank (2019) desirable working abilities for the future in the context of CBL.

Abilities	Authors
Technological know-how	[22,23,29,31,32,34]
Problem-solving	[20,22,23,25,29,31,38]
Critical thinking	[20,22–25,31,35]
Soft skills (perseverance, collaboration, empathy, etc.)	[20,22–25,29,31,33,34,38]

The flexibility of CBL allows its integration with other frameworks or techniques to better fit different disciplines, courses and institutional needs. A recent review of the literature identified that the flexibility of CBL "paves the way for more innovative hybrid approaches to student-led learning, vital for many higher-level institutions" [21] (p. 16). However, to the best of our knowledge, adaptations of CBL in OM education have not been documented before.

Therefore, this study presents an intervention aimed at facilitating the adoption of CBL in OM education. The intervention builds on the CBL framework (see Figure 1) and is augmented in two ways. First, we draw on concepts from the fields of creative problem-solving [39] and reflective learning [40] to better operationalize stages 2 and 3 (investigate and act) and the reflections required throughout all the stages of the CBL framework. Second, we integrate OM concepts by including the five performance objectives proposed and popularized by Greasley [41], Paton [42] and Slack and Brandon-Jones [43] as criteria to guide the investigation (stage 2) and the evaluation of the solutions in stage 3. A detailed explanation of the intervention is provided in the following section.

3. Research Methods: CBL Intervention in OM

The general purpose of this research was to design, implement and evaluate a CBL intervention to support students understating of Industry 4.0, whilst developing key desirable working abilities for the future [19]. This required the design and implementation of an augmented CBL framework tailored to OM education. We were particularly interested in learning more about how students experienced the CBL approach within an OM module.

3.1. Designing the Intervention

As indicated in Figure 1, the Challenge-Based Learning framework comprises three stages [29]. Stage 1 (engagement) requires a systematic process of analysis to identify potential challenges [44]. Six businesses provided real-life challenges that were deemed viable and relevant to OM by the academics. This judgment was based on all the proposed challenges being related to the operations management function within the businesses and had a common expectation that the solutions would be based on the application of Industry 4.0 technologies. Table 2 provides a sample of the challenges that were used.

Table 2. Sample of the challenges provided to students.

Size of Company	Type of Industry	Challenges
Micro	Food and beverage	Better and more consistent social networking/website updating or improvements/advertising
Micro	Non-profit	To develop a safe logistics plan for the collection and redistribution of food from suppliers and to food champions.
Small	Printing and Publishing	How can information available and/or accessible be used to increase sales, without too much human participation?
Small	Manufacturing	Launch of fully automated production of artwork for online customized products.
Large	Education	How can digital technologies support current operations and reduce environmental impact in the (Business School) Building?
Large	Defense	To explore and recommend potential commercial applications, which exploit the inherent strengths of a particular piece of equipment used for military purposes.

Based on the challenges identified, the academic team prepared a series of guiding questions, activities and resources to support students in their investigation, as suggested in the CBL framework [26]. Furthermore, students were given briefings that explained their allocated challenges and businesses' contact information.

Stage 2 (investigate) was focused on 'challenge structuring' or acquiring knowledge to develop solutions to the given challenges. This stage was supported by the academic team via guiding questions, guiding activities and guiding resources. Noticeably, students worked on recognizing operations components, their interactions and their impact on a set of performance objectives. Specifically, students were asked to consider how Industry 4.0 technologies could affect the performance objectives of the operation under study.

They were advised to focus on potential solutions that could positively impact at least one performance objective. The performance objectives chosen were those widely accepted in Operations Management literature—namely, the cost, dependability, flexibility, quality and speed [41–43]—and directly linked to the module's learning outcomes. Their relevance is also justified here as it has been recognized that the technologies underpinning Industry 4.0 can improve competitiveness of firms through the improvement of such performance objectives or at least alleviate the traditional operations trade-offs between them [8].

Finally, stage 3 (act) comprised three main activities: 'Brainstorming solutions', 'Evaluating and selecting a final solution' and 'Challenge reflection'. To conduct the two first activities, students were supported with resources and a lecture concerning creative problem-solving techniques, which are suitable when a given goal (i.e., challenge) exists but there is uncertainty regarding how to proceed [39]. This uncertainty has been previously documented as a barrier in CBL, as students may lack the skills to take informed decisions regarding the best or most innovative solutions [20,31].

Therefore, the inclusion of creative problem-solving techniques aimed to mitigate this issue. As the focus of this CBL exercise was Industry 4.0 technologies, a set of guiding resources was offered, including a lecture on Industry 4.0 and its impact on OM and other relevant digital materials (i.e., journal articles). To improve the relevance and significance of their proposed solutions, they were asked to justify how their solutions supported the improvement of at least one of the five performance objectives.

Once a solution was identified and validated, students conducted a reflection guided by the Gibbs' reflective cycle [40] as part of the last activity of stage 3, 'Challenge reflection'. This reflection comprises six steps: description, feelings, evaluation, analysis, conclusion and action plan. Gibbs' model was chosen as previous studies have found it to support reflective learning from challenging experiences [45] and encourage reflective practices within interventions based on experiential learning [46–48].

Finally, students were asked to share their solutions with the wider community. For this purpose, each team prepared a poster and presented it in a public event, where executives from the business partners and academics interacted with the teams and asked questions on the different experiences involving the CBL intervention. As a graphic summary, the different elements of the CBL intervention are depicted in Figure 2.

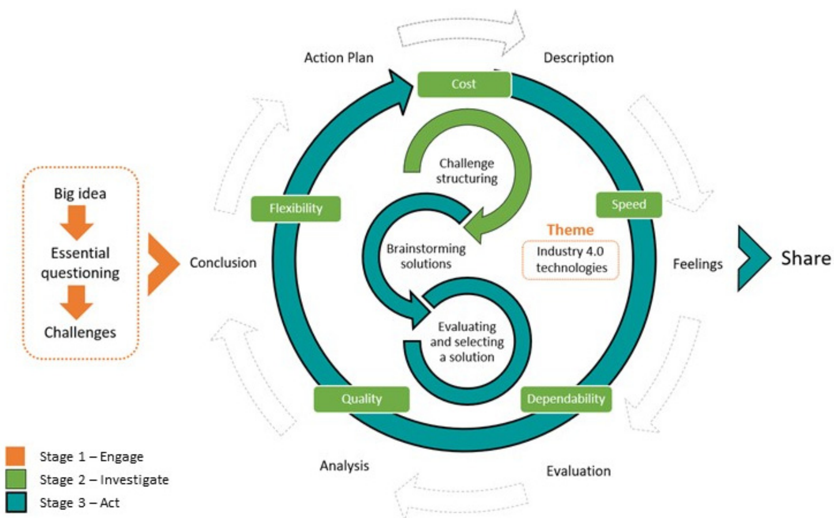

Figure 2. CBL intervention in operations management.

The augmented CBL framework incorporates a series of add-ons to provide students with a learning environment where to acquire hard and soft skills associated to an Industry 4.0 working environment. These add-ons can be seen in Figure 3.

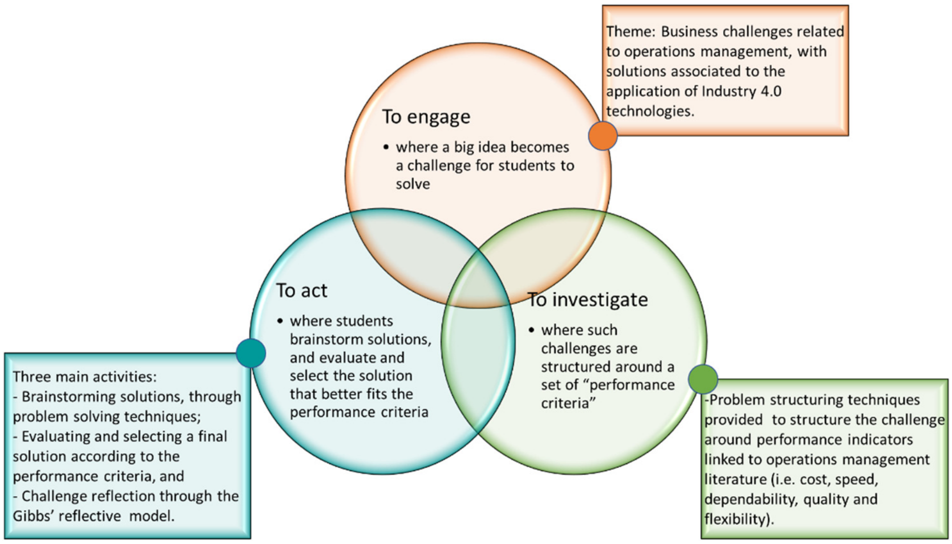

Figure 3. Augmented CBL framework for Operations Management.

3.2. Implementing the Intervention

CBL was implemented in two terms from September 2019 to May 2020 at Lincoln International Business School, within the Operations Management module. The module consisted of 36 h class contact (24 h of lectures and 12 h of seminars), 48 h of CBL group work and 66 h of self-study. This is a core module for second-year students, who are enrolled in most of the undergraduate programs offered by the Lincoln International Business School. The first academic term comprised 99 students and the second term 203 students (see Tables 3 and 4). During a period of 12 weeks, students worked in teams of between five to eight students to solve the challenges. The first academic term comprised 16 teams, and the second term was 35 teams.

Table 3. Term 1: September 2019–December 2019.

Courses	Students
BA (Hons) Business and Enterprise Development	9
BA (Hons) Business and Finance	43
BA (Hons) International Business Management	44
Department of People and Organisation Erasmus Exchange Program	2
School of Social and Political Sciences Erasmus Exchange Program	1
Total	99

Students worked following the CBL intervention during most of the seminars that took place before week 10. They provided weekly informal (verbal) progress reports to tutors and had the opportunity to receive formative feedback along the way. Summative assessment was provided in week 10, when students shared their solutions (via poster showcases) with the public, academic staff and business partners. Additional summative assessment followed the format of individual essays, where students reflected on their team solutions and the experiences collated during the CBL exercise.

Table 4. Term 2: January 2020–May 2020.

Courses	Students
BA (Hons) Business Studies (with Professional Practice)	36
BA (Hons) Business and Management (with Professional Practice)	135
BA (Hons) Business and Marketing (with Professional Practice)	28
BA (Hons) Sports Business Management	3
BSc (Hons) Events Management	1
Total	203

3.3. Data Collection and Analysis

To evaluate the proposed CBL intervention (see Figures 2 and 3), a set of data was collected from the reflections expressed in the students' posters. Such posters were submitted via Blackboard in week 10. A total of 7487 words were recovered from the 51 posters submitted. Before the analysis, data was anonymized to protect students' confidentiality.

Document analysis (DA) was adopted as a research method in this study to recognize emerging patterns across the data. DA is a form of qualitative research that involves the selection, review, evaluation and synthesis of documents to gain understanding and empirical knowledge, typically by organizing selected data into themes or categories [49]. This method was chosen because of several advantages such as efficiency in terms of time [49], availability of data and cost-effectiveness [50] and the opportunity to gain access to the views of the whole population.

The data analysis process was based on a six-phase thematic analysis approach [51] using NVivo software. This process is summarized in Figure 4. Thematic analysis is particularly suited for document analysis [49] as it can highlight the similarities and discrepancies among the views of different research participants [52]. The analysis involved an iterative process of coding, categorization of codes into overarching themes and naming of final codes and themes. As suggested by Guest et al. [53], we used several techniques for the identification of themes, such as 'repetition' or looking for concepts that reoccur through the documents, 'linguistic connectors' or searching for phases that denote causal relations and 'silence/missing data' or the absence of an emerging theme that was expected.

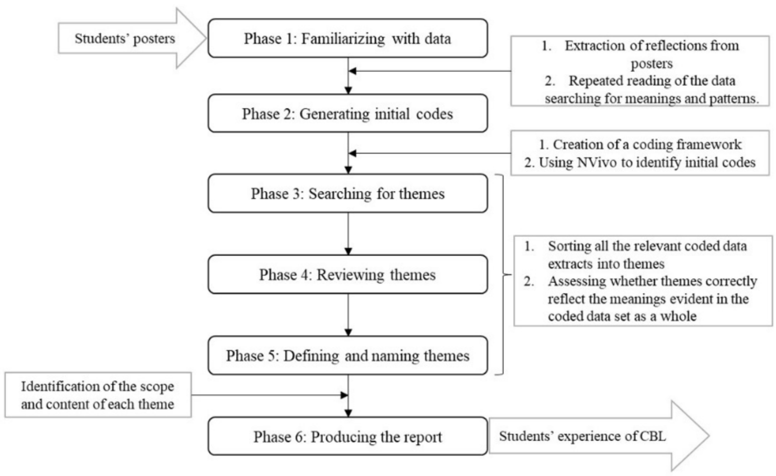

Figure 4. Thematic analysis process (adapted from Braun and Clarke, 2006).

4. Results

The results identified a range of themes and codes regarding how students experienced CBL. Overall, some similarity exists among the experiences reported by different teams. Using a six-phase thematic analysis [51] (Braun and Clarke, 2006) and NVivo 12 software, we identified four main themes that relate to (1) 'The challenge', (2) 'Teamwork', (3) 'Feelings' and (4) 'Challenge-based learning' (See Figure 5).

Figure 5. The main themes identified in the six-phase thematic analysis.

The overarching themes and emerging codes within each theme are summarized in Table 5.

Table 5. Summary of the emerging themes and codes.

Themes	Codes	Illustrative Quotes
1. The challenge	Industry 4.0	"It gave us the chance to look into industry 4.0 and what possibly opportunities it can bring to us as future graduates"
	Meeting with company	"As the challenge continued, we gained more clarity on the task as a result of performing extra research on the company and meeting the owner..."
	Techniques	"We have learned new models that have helped us to evaluate the best solution. Ideas that seem good aren't always as good after evaluation"
	Theory and materials	"For future reference, it should be further attempted to analyze topics from lectures by partaking in more further reading"
2. Teamwork	Communication	"We were able to come together to discuss ideas and tackle opposing opinions. The task required a lot of discussion before any meaningful progress was made"
	Meetings	"We should have made more of an effort to meet every week to make more progress throughout"
	Planning	"For future challenges, a detailed plan as well as appropriate time spent on each section should be planned before getting our hands on the challenge"
3. Feelings	Confusion	"To begin with we felt confused and uncertain in relation to the challenge structuring as well as working with a real-life company as we had not done this before"
	Apprehension	"There were feelings of apprehension, because the nature of the challenge tested our knowledge for which we had no prior experience"
	Confidence	"...the more research we did the more confident we felt about the challenge"
	Motivation	"Although our motivation was present at the beginning it definitely got stronger as a group as we progressed"
	Sense of achievement	"There was a sense of achievement when all the work was complete"
4. Challenge-based learning	The approach	"Took a while to adjust with it being so different from other modules"
	Real-life challenge	"The experience was helpful as it put us in a real-world situation and made us think outside the box for creative and realistic solutions to the challenges put in front of us"
	Research	"We think that most of this project went smoothly due to our detailed research and understanding of the challenge"

4.1. The Challenge

The first theme that emerges from the thematic analysis, encompasses codes representing specific aspects of the intervention proposed in this paper but do not necessarily form part of every CBL intervention. For instance, the proposed intervention revolves around the use of digital technologies (as part of Industry 4.0) to solve challenges; however, this is not a prerequisite for the use of CBL.

Furthermore, the proposed intervention considers the use of problem-solving techniques for identifying solutions to challenges, whereas the original CBL framework does not necessarily require the use of such techniques. Table 5 highlights the main aspects of the proposed intervention from students' perspectives. These were divided into four categories: 'Industry 4.0′, 'Meeting with the company', 'Poster', 'Techniques' and 'Theory and materials'.

Students found the use of Industry 4.0 as the central theme of the CBL exercise to be useful as it expanded their knowledge of digital technologies. It also increased their understanding regarding the potential of Industry 4.0 to solve challenges that businesses are currently facing. Furthermore, students explained that the CBL exercise helped them to develop a more critical view regarding the benefits of Industry 4.0 but also the disadvantages in the context of small businesses. Students provided the following comments:

> "Good aspects of this experience were the ability to develop our knowledge on how technology can be used to help reduce environmental footprint" (S23).

> "We gained insight into a local business and what it offers to those within the area. As well as, increased knowledge on industry 4.0 and how it can benefit small businesses and the advantages as well as the disadvantages" (S12).

Students found the meeting with the company beneficial, to gain a better understanding of the task at hand. Some students commented that through the meeting, they were able to clarify ideas and conduct a better-informed decision-making process.

'Techniques' was a recurring code. This code encompasses many aspects related to the problem-solving techniques that students were asked to use in order to find a solution for their challenge. Many students found problem-solving techniques useful, to gain a better sense of the scenario at hand, generate solutions and develop a more critical approach to the evaluation of solutions. Some reflections also showed that students discovered the importance of understating how the techniques work, using a wide variety of techniques and investing time in understanding the challenge before looking for solutions.

> "By using two brainstorming techniques we were able to successfully generate a wide range of solutions" (S42).

Another common theme was related to theory and materials. In this regard, it was often mentioned that if faced with a similar experience in future, students would do additional reading regarding OM theory but also around the topic of their allocated challenge, before attempting to come up with solutions. This may indicate that many students focused more on the practical side of the task (i.e., coming up with solutions to the real-life challenge) and less on trying to understand the theory of OM and using their theoretical understanding to analyze and solve the challenge.

> "We would do additional reading in order to even further improve our knowledge about operations management so we can provide better solutions backed up with more academic material" (S51).

4.2. Teamwork

Codes related to soft skills showed a lot of repetition. Three main codes emerged within the theme 'Teamwork'—namely, 'Communication', 'Meetings' and 'Planning'. Most shortcomings regarding team performance were attributed to these three elements of teamwork. Students suggested that they should have been more organized in the early stages of group work, which, in turn, would have made the whole process more efficient and would have ensured that the workload was split more evenly.

Regarding 'Communication', students held contrasting views. On one hand, some students commented that effective communication enabled the problem-solving process and improved their ability to tackle the challenge. Some alluded to the importance of adopting a democratic approach for decision-making. On the other hand, some students felt that a lack of effective communication created a stressful atmosphere and undermined their ability to progress and complete the task in a more efficient way:

> "We followed a democratic style to decisions. This meant we were able to generate more ideas as everyone had equal input and no one person was dictating on what ideas was good or bad ones" (S2).

> "As a group we felt rather stressed as at times communication would be poor which made work difficult to complete and sometimes it felt as if we were stuck due to issues with the group" (S45).

In terms of 'Meetings', views were also split between those who found it difficult to meet outside of the seminar session, due to busy schedules, and those who attributed their success to their ability to meet at least once or twice every week. Students who met regularly (i.e., each week) found it beneficial in terms of organization, communication and meeting deadlines. Others expressed their intention to preplan group meetings and create time scales to improve productivity if faced with a similar challenge in the future:

> "We could have had a more rigid time and place for everyone to meet which would have made it easier to work on the poster together and at once" (S19).

Another recurring code relates to 'Planning', which included aspects such as organization, task delegation and time management. Students believed that their success (or lack of) in completing the challenge was (among other things) due to their time management skills and their ability to be organized, particularly during the early stages of group work. Several teams also attributed the successful completion of the task to their ability to delegate or divide the work based on each other's strengths. A team reflected on their poor time management skills and partly attributed their difficulties to global disruptive events (i.e., the beginning of the COVID-19 pandemic).

> "We have learned that we had good time management skills which enabled us to work efficiently and consistently" (S4).

4.3. Feelings

Students' contrasting 'Feelings' were extensively reported. Some students reported 'positive feelings' from the start of the term, such us excitement, motivation, interest, optimism and confidence. Others explained that even though they remained neutral at the beginning, they slowly gained confidence as the module progressed. This was mainly attributed to the research that they conducted about the allocated challenge and the subject area, as well as meetings with the tutor that helped to clarify doubts.

> "As we began to explore the project and concept more, we gained confidence in our ideas and our knowledge around the subject area" (S13).

On the other hand, negative feelings such as 'Confusion' and 'Apprehension' were also experienced at the beginning, mostly because students were not familiar with the business partners and their operations or the CBL approach and had never worked with a real-life challenge. Some students explained that there was uncertainty regarding what they were required to do, particularly during the first few weeks. Other students mentioned that they felt lost as there was a wide variety of problem-solving techniques to choose from, and they found it difficult to arrive to innovate solutions or choose the best.

> "Main negative was the confusion surrounding the task, especially towards the beginning prior to the meeting with the owners of the business" (S25).

Interestingly, most students who reported 'negative feelings' at the beginning, explained that those feelings gradually shifted as the term progressed and ultimately transformed into 'positive feelings', such as 'Sense of achievement' and 'Confidence'. Several reasons were given for this change. Some explained that confidence increased because of good teamwork. Once students had the chance to familiarize as a team and an effective team dynamic was accomplished, they became confident in their ability to finish on time and produce feasible solutions. They also mentioned that as their knowledge of their allocated business/challenge grew, through research and meetings with businesses, their confidence and motivation improved. Lastly, they suggested that confidence was also boosted by meeting with their tutors to clarify doubts and questions. Finally, students reported a sense of achievement after successfully completing the challenge.

> "Everyone felt a sense of contribution and boosting motivation when all the work was complete" (S25).

4.4. Challenge-Based Learning

Several aspects of the CBL approach were discussed by students. Aspects inherent to CBL, as an educational approach, were grouped under the 'Challenge-based learning' theme, including 'The framework', 'Real-life challenges' and 'Research'. 'The framework' encompasses aspects that characterize CBL according to students' views. Students used words, such as "rewarding", "creative" and "innovative", to describe their experience of working with CBL. These characteristics seemed to translate into satisfying experiences albeit challenging, as some students also acknowledged that it took them a while to adjust to CBL as it is quite different from traditional learning and involves a higher level of uncertainty.

> "It is worth noting that no group member had experience in a task similar to this before, so many will take positives from this task into the future with other projects, both inside and outside of the university environment" (S11).

Students seemed to value the use of a real-life challenge over a hypothetical situation or case study, which according to them, made the experience more unique, interesting and professional. Students particularly welcomed the opportunity to increase their knowledge about local businesses and what they have to offer to the local community. Some students also appreciated the opportunity to observe first-hand how concepts of operations management are applied in a real-life situation, from developing a new product to understanding the impact of operations on the environment. Students also reported that the opportunity to test problem-solving techniques in a real-life situation made them think outside the box for creative and realistic solutions that could be beneficial for society:

> "The experience was helpful as it put us in a real-world situation and made us think outside the box for creative and realistic solutions to the challenges put in front of us" (S8).

> "What went well in this challenge was being able to delve into a real-world scenario to solve an operational conundrum, which will serve as valuable experience for our career" (S21).

Another recurring code relates to 'Research'. This was an expected result considering that stage 2 of the CBL framework is dedicated to investigation. In this stage, students are encouraged to acquire the knowledge that will later build the foundation for solutions. What was more unexpected, was that students highlighted the importance of this stage and attributed their success to their ability to perform thorough investigations.

> "...we felt it was very important to research all the solutions extensively in order to undertake an accurate evaluation. We felt this was key to completing the challenge effectively and successfully" (S44).

> "We were able to collate ideas from different perspectives and knowledge within the group, for example one of our members has a brother who works at ..., therefore he had a source of knowledge we could adapt for our context" (S34).

5. Discussion

Students reported favorable levels of knowledge acquisition regarding OM and Industry 4.0. Particularly, students found the use of industry 4.0, as the central theme of the CBL intervention, to be useful as it increased their knowledge of digital technologies and helped them to develop a more critical view regarding the benefits and disadvantages of Industry 4.0.

Many students agreed that the CBL intervention supported the development of their problem-solving skills. This finding is in line with current literature which acknowledges the ability of CBL to develop such skills in students [23,32,38]. In this regard, the evidence collected here suggests that the augmented framework proposed in this study helped to better operationalize stage 2 (investigate) and stage 3 (act) by offering students a set of problem-solving techniques, which was a recurring theme in the analysis. Students explained that they discovered the importance of using a wide variety of techniques to generate and evaluate a vast range of solutions. Existing CBL literature only refers to the development of problem-solving skills but does not provide a toolset like the one proposed in this research.

This is an important addition as it could help mitigate students lack of skills to make better-informed decisions regarding the best or most innovative solutions, which has been previously identified as a barrier in CBL [20,31].

Previous literature has also documented issues related to teamwork in a CBL atmosphere. Membrillo-Hernández et al. [23] hinted that the level of uncertainty involved in CBL highlights the importance of critical thinking, planning ahead, resilience and teamwork. Furthermore, a study by López-Fernández et al. [33] found that students' relationships with their colleagues were not as good after a CBL intervention. This is to be expected when a learning approach involves teamwork but also emphasizes the importance of supporting students in the training of their soft skills.

Our findings suggest that students attributed their success (of lack of) to several soft skills—namely, teamwork, planning, time management, task delegation and communication, particularly during the early stages of group work. Here, it is important to acknowledge that the teaching term was disrupted by a national lockdown imposed in the UK due to the COVID-19 pandemic. As a result, the last two weeks of teaching were delivered remotely. This could have had a negative impact on the students' ability to perform teamwork and manage their time effectively.

Students' contrasting feelings were extensively reported. This may be an outcome of the integration of Gibbs' reflective cycle into the augmented CBL framework, as it prompts students to explore their feelings and thoughts during a given experience [40]. Some students communicated positive feelings from the start of the term, such us excitement, motivation, interest, optimism and confidence. Similar positive feelings were documented by Johnson et al. [30], who suggested that these feelings might be triggered by the prospect of working on a real-world challenge, doing research and making a difference in the community.

On the other hand, negative feelings were also reported, including confusion and apprehension. This finding is consistent with the study conducted by Membrillo-Hernández et al. [23] who acknowledged that students may find the uncertainty and self-learning involved in CBL to be challenging in the beginning. Binder et al. [31] have reported a similar issue and recognize that some students find it difficult to understand the CBL approach. Students also reported a sense of achievement after successfully completing the challenge. This is in line with findings from López-Fernández et al. [33] who also observed an increase in intrinsic motivational levels after a CBL intervention, particularly a stronger sense of accomplishment.

Students appreciated the opportunity to observe first-hand how concepts of operations management are applied in a real-life situation, which according to them, made the experience more unique, interesting and professional. This is in line with previous findings which suggest that students' satisfaction increases when faced with real-life problems [23]. Other studies have also documented positive impacts on technical skills [33], motivation, engagement, complex thinking and propensity to take risk [35].

Our findings suggest that students value the opportunity to think outside the box for creative and realistic solutions that can have a real impact on the community and businesses. Even though the five performance objectives were not explicitly mentioned in the reflections, they guided the evaluation and selection of solutions in the stage three of the proposed framework. The businesses and academic staff rated the solutions based on their potential impact on the five performance objectives. It is suggested that this provided a more robust framework for students to make a better-informed decision.

Some students reported that they were also able to further apply other skills, such as research. Many students reflected on the importance of conducting extensive research before attempting to find solutions to the challenges, which indicates the application of critical thinking skills. This is an important aspect of CBL as it allows students to contextualize learning and create a firm foundation for feasible and sustainable solutions [29].

Furthermore, this process allows students to connect research to the challenges within their communities, which facilitates a stronger connection between what students learn in the classroom and what they experience outside of it [32].

In summary, the evidence collected here supports previous observations on CBL; however, it also extends CBL benefits for its use within OM classrooms, specifically if there is the intention of supporting the training of key desirable working abilities for the future, including critical thinking, problem-solving, technological know-how and a set of soft skills.

6. Conclusions

Approaches, such as CBL, PBL and POL, provide guiding resources for students to succeed in a task. However, CBL pushes students' learning further as it allows a degree of uncertainty and freedom for students to exploit their creativity and innovation, which translates into a rewarding experience. The findings suggest that students' experiences were characterized by an enhancement of their ability to understand OM in real-life settings and the potential that Industry 4.0 technologies represent in devising OM solutions. The CBL intervention was also conducive to students' application of soft skills. Our findings indicate that CBL provided an environment for training in soft skills, such as communication, planning, problem-solving, task delegation and team building and acquiring research skills.

This study contributes to the advancement of knowledge on the use of CBL in the field of Operations Management in higher education. From an academic perspective, this study extends previous CBL research conducted in other disciplines by proposing and evaluating an augmented framework that integrates concepts from OM, creative problem-solving and reflective practice. To the best of our knowledge, our research is the first to propose, implement and evaluate an intervention for the use of CBL within Operations Management. Thus, this study provides the first blueprint to implement CBL within an OM module in the UK and potentially in other settings. Therefore, the findings can serve as a reference for the further implementation of CBL within OM education, particularly in business schools.

Our findings suggest that there are benefits from the timely introduction of CBL, both in terms of knowledge acquisition and training of key desirable working abilities for the future; namely, technological know-how, problem-solving, critical thinking, soft skills (such as communication, planning, task delegation, team building, decision-making and self-reflection) and research skills. Additionally, our findings suggest that students found some aspects of CBL, such as the increased uncertainty and teamwork, to be challenging; however, overall, they were satisfied with the experience and benefitted from it. Therefore, this study can serve as guidance for the creation of novel OM experiential environments, closer to real-life, where learners might apply and advance their knowledge and skills to cope with rapidly changing workplaces.

We consider that CBL and the framework proposed here can contribute towards mitigating the current challenge of adapting OM education to better fit the Industry 4.0 working environment. By embedding Industry 4.0 via CBL, the relevance of what is taught within the classroom is increased, translating into the delivery of Industry 4.0 knowledge and crucial soft skills training. Such an approach can help towards reducing the current lack of digital culture of future OM graduates and facilitating the adoption of Industry 4.0 technologies within businesses. Thus, CBL and the framework proposed here should be considered as an important tool to upgrade the current and future OM curricula to train and familiarize future generations of students with Industry 4.0 innovations.

This study is based on an intervention in a single course within a business school in the UK. Whilst the intervention might be easily applicable to other OM courses, the findings on students' experiences might not be directly generalizable to other courses or disciplines.

Certain aspects of the course where CBL was implemented, such as the form of assessment (i.e., groupwork) and thematic orientation (i.e., Industry 4.0), might have influenced the findings to a great extent. However, the course where CBL was implemented is comparable to other OM courses within business schools in the UK, in terms of both the student demographics and timeframes. Furthermore, the comparison of existing CBL literature and the findings from this research did not show contradictions, which provides confidence in the ability to generalize the results beyond the context of this study.

Author Contributions: Conceptualization, E.V.-P. and R.M.-V.; methodology, E.V.-P. and R.M.-V.; formal analysis, R.M.-V.; investigation, E.V.-P. and R.M.-V.; data curation, E.V.-P.; writing—original draft preparation, E.V.-P.; writing—review and editing, R.M.-V. and R.T.-A.; project administration, E.V.-P.; funding acquisition, E.V.-P. and R.T.-A. All authors have read and agreed to the published version of the manuscript.

Funding: The authors would like to acknowledge the financial support of Writing Lab, Institute for the Future of Education, Tecnologico de Monterrey, Mexico, in the production of this work (*Los autores desean agradecer el apoyo financiero de Writing Lab, Institute for the Future of Education, Tecnologico de Monterrey, Mexico, en la producción de este trabajo*). This research has been also funded by the EU Interreg COM3 project [Grant number 38-2-3-19], the Chartered Institute of Logistics and Transport (CILT), the Lincoln International Business School Teaching Innovation Fund, the Lincoln Higher Education Research Award (LHERA) and the Industrial Digitalisation Project (UoL initiative funded by HEFCE), during one or several of the different stages.

Institutional Review Board Statement: Ethical review and approval were waived for this study since at the Institution this project is classified as a "Research without risk", i.e., these are studies that use retrospective documentary research techniques and methods and those in which no intentional intervention or modification is carried out in the physiological, psychological and social variables of the individuals participating in the study, among which the following are considered: questionnaires, interviews, review of clinical files and others, in which they are not identified or sensitive aspects of their conduct are not addressed.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Vilalta-Perdomo E; Michel-Villarreal R. 2022. Integrating Industry 4.0 in higher education using challenge-based learning: An intervention in Operations Management; Mendeley Data; V1; DOI:10.17632/xxksktbr82.1.

Conflicts of Interest: The authors declare no conflict of interest.

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